

Blackbody radiation and greenhouse effect

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Details

Type: Integrated unit with five separate interactive computer-based activities.

Length 3-4 45 minute periods

Content Area/Course: Earth science, Physics, and Chemistry

Targeted Grade Level: 8-12 (adaptable)

Prerequisite Knowledge/Skills: General internet navigation: basic understanding of atmospheric science

Technology/web resources: Internet access, Java-enabled

Thinking skill development: Comprehension, synthesis, evaluation

NASA resources used:

Description

Students will use graphical tools to understand blackbody radiation, identify different spectrum ranges, learn about the interaction of atmospheric gases with radiation of different wavelengths, and recognize the relationship between greenhouse gases and global average temperature. This unit provides a foundational understanding of the greenhouse effect and its role in controlling Earth's temperature.

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Teaching Notes

Grade Level

High school, but could be adapted to 8th grade.

Learning Goals

After completing this unit, users will be able to:

- Identify the important wavelength spectrums associated with solar and terrestrial radiation
- Associate temperatures of objects with their electromagnetic emission wavelengths
- Recognize that different gases interact with radiation of different wavelengths differently
- Relate greenhouse gas concentrations to temperature
- Communicate their findings orally using appropriate climate change and Earth science vocabulary.

Rationale

This unit helps students understand the basics of the greenhouse effect and the relationship between greenhouse gas concentrations and global temperatures. Students will be able to understand terminology related to solar and terrestrial radiation. Students will be able to recognize different greenhouse gases and the mechanism by which they interaction with terrestrial radiation.

Students will use a variety of web based visualization tools and Excel to plot data obtained from these tools .

Key Concepts and Vocabulary

Black body: A finite-sized body that absorbs all incident electromagnetic radiation.

Electromagnetic (EM) radiation: Electromagnetic radiation is produced as a result of conversion of a body's internal thermal energy to electromagnetic energy – i.e., energy associated with the motion of charged particles. EM radiation behaves both like a stream of massless particles and waves as it is transmitted through a medium.

Shortwave radiation: Usually refers to the electromagnetic radiation in near- visible and visible wavelengths (0.3 - 4 μm),– i.e., wavelengths where most of Sun's energy is concentrated.

Longwave radiation: Usually refers to the electromagnetic radiation in infrared and near-infrared wavelengths (longer than 4 μm) – i.e., wavelengths where most of Earth's radiative energy is concentrated.

Anthropogenic emissions: Emissions resulting from human activities.

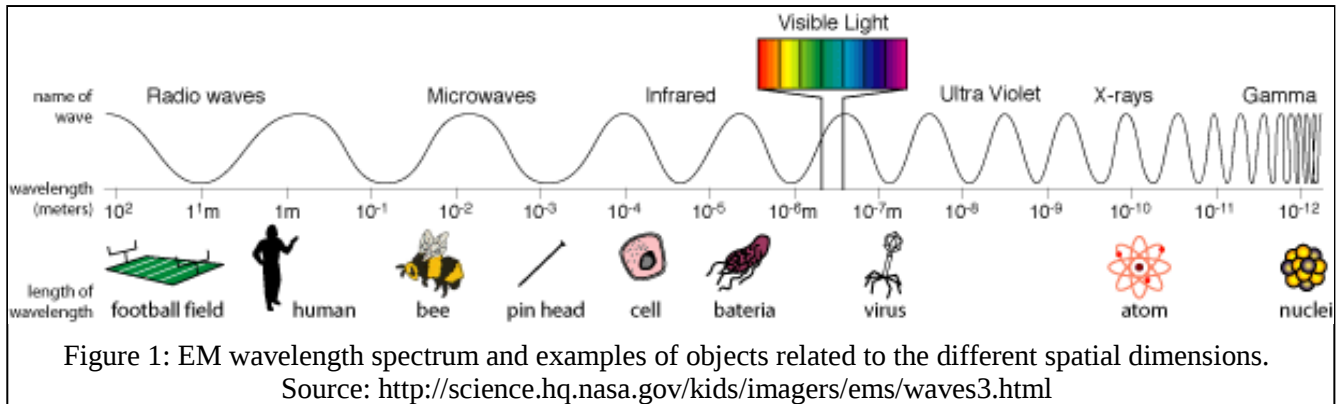
Greenhouse gas (GHG): A gas that absorbs energy in wavelengths corresponding to long-wave radiation.

Greenhouse effect: The process of energy absorption and re-radiation by the GHGs in the atmosphere.

Background Information

To understand the role of greenhouse gases in global climate change, it is important to understand the basics of blackbody radiation and the interaction of greenhouse gases with Earth's long-wave radiation. An introductory PowerPoint presentation on this topic is available [on the website](#).

All bodies emit energy in the form of electromagnetic (EM) radiation. The sun's energy reaches Earth in the form of light – a form of EM radiation (Figure 1). We feel the warmth from a fireplace even with a glass barrier because of EM radiation. The warm coil on the stove glows because it emits EM radiation and the coil's heat is felt at a distance because of EM radiation. Heat and light are both forms of electromagnetic radiation. Other forms of electromagnetic radiation include: x-rays, gamma-rays, and radio waves. The different forms of EM radiation correspond to different energies and wavelength ranges as illustrated in Figure 1.



A black body is a body that absorbs all radiation that it receives and emits radiation in all wavelengths. The net intensity of the radiation emitted by a blackbody is dependent on its temperature (intensity is proportional to T^4), with hotter bodies emitting greater amounts of radiation. While blackbodies emit radiation over all wavelengths, a significant fraction of their emitted energy is concentrated in a limited range of wavelengths. The wavelength corresponding to the peak intensity of emission decreases with increasing temperature.

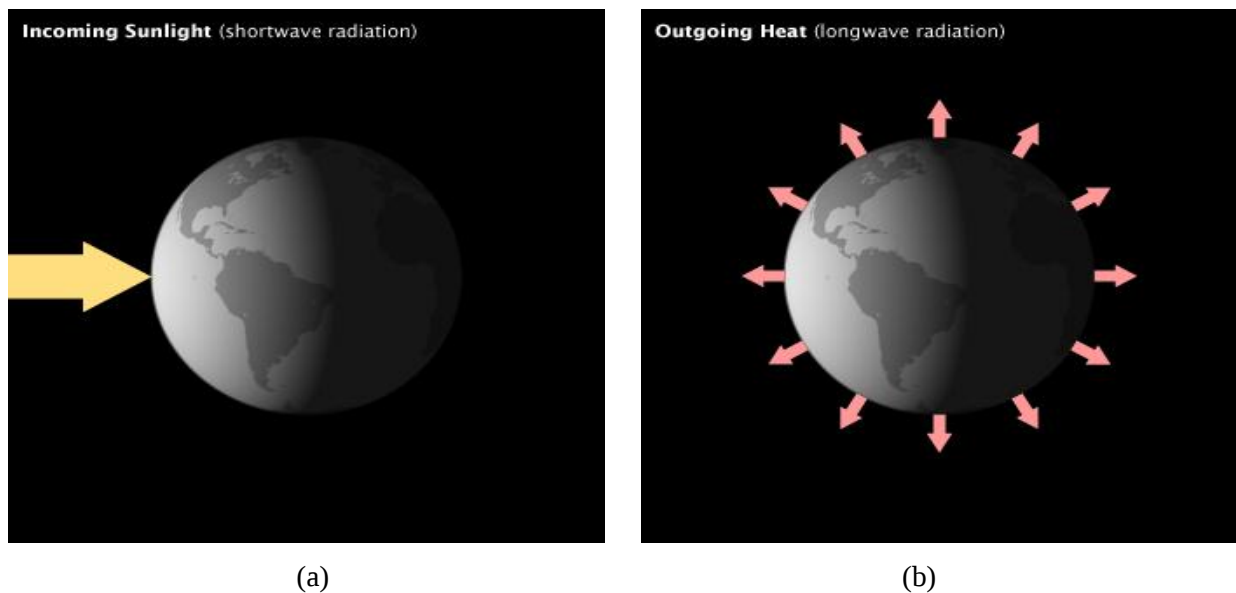
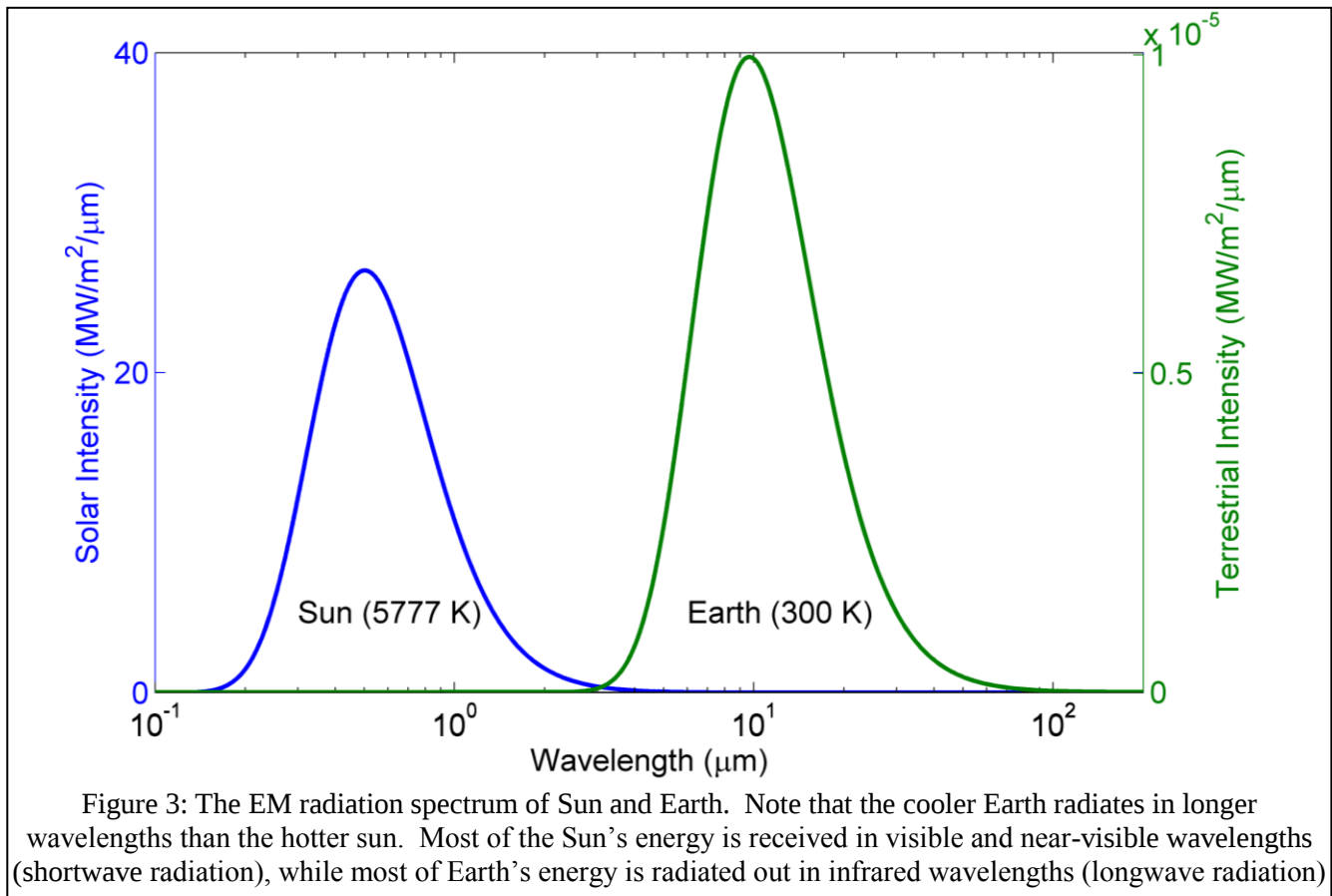


Figure 1: (a) Sun's EM radiation received by Earth. (b) And the re-radiation of this energy by Earth as a blackbody. Source: <http://earthobservatory.nasa.gov/Features/EnergyBalance/>

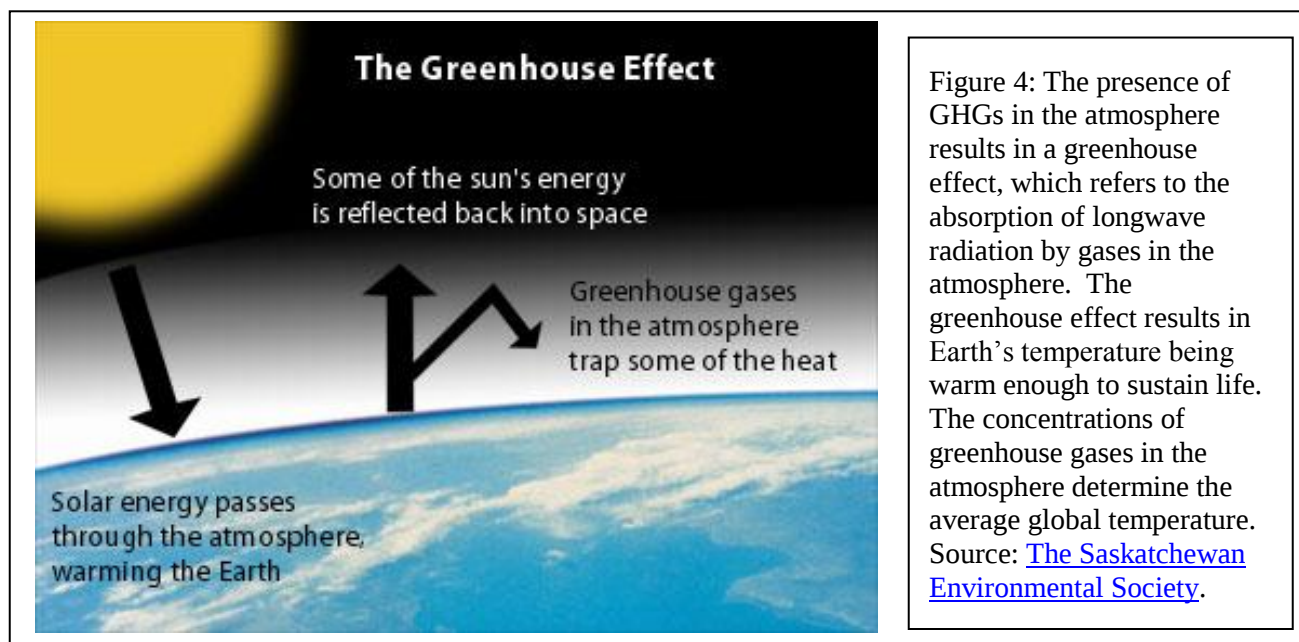
Sun and Earth can both be considered black bodies in analyzing their radiative properties. The EM radiation from Sun is primarily in short or visible wavelengths ($0.4 - 0.7 \mu\text{m}$) corresponding to the Sun's high temperature ($\sim 5777 \text{ K}$), while the EM radiation associated with Earth's emission to space is primarily in the infrared wavelength range ($1-10 \mu\text{m}$), corresponding to its cooler temperature ($\sim 298 \text{ K}$; Figure 3). As Earth's temperature is largely in equilibrium, the incoming short-wave radiation should be balanced by the outgoing long-wave radiation.

Not all the long-wave radiation emitted by Earth escapes to space. Some gases in the atmosphere can absorb Earth's long-wave radiation and heat up the surrounding air by collisions with the neighboring molecules. The heated layer can then radiate energy back to Earth's surface. This effect of trapping the outgoing long-wave

radiation and warming up Earth's atmosphere and surface is referred to as the Greenhouse effect and the gases that absorb long-wave radiation and create the greenhouse effect are called Greenhouse gases (GHGs).



Without GHGs, Earth's temperature would be too cold for humans ($\sim 0^{\circ}\text{F}$ rather than 60°F that we have currently). Thus, GHGs are essentially for maintaining life on Earth. The most abundant GHG in the atmosphere is water vapor. The concentration of water vapor in the atmosphere is a consequence of Earth's temperature, existing in equilibrium with liquid water and ice on Earth's surface. The atmospheric water vapor concentration is not directly controlled by anthropogenic emissions.



Some of the important greenhouse gases with anthropogenic sources are: Carbon dioxide (CO_2), Methane, (CH_4) and Nitrous Oxide (N_2O). The concentrations of these gases can critically control the extent of Earth's long-wave radiation trapped in the atmosphere. Anthropogenic sources of these gases are primarily from the combustion of fossil fuels. The [concentrations of greenhouse gases have steadily increased](#) since the Industrial Revolution. A corresponding increase in the average global temperatures has also been observed.

Key References:

General Meteorology applets: <http://people.cas.sc.edu/carbone/modules/mods4car/index.html>

EPA's Climate change site: <http://epa.gov/climatechange/index.html>

NASA's climate change site: <http://climate.nasa.gov/>

NASA greenhouse effect:

http://earthobservatory.nasa.gov/Experiments/PlanetEarthScience/GlobalWarming/GW_Movie3.php

US greenhouse gas inventory: <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

Global greenhouse data: <http://www.epa.gov/climatechange/emissions/globalghg.html>

Greenhouse effect (NCAR): http://www.ucar.edu/learn/1_3_1.htm

Greenhouse gas concentrations: http://cdiac.ornl.gov/pns/current_ghg.html

Learn about Infrared: http://coolcosmos.ipac.caltech.edu/cosmic_kids/learn_ir/index.html

Instructional Strategies

General Approach

This unit has multiple parts that are best done with students in pairs or groups of 3. The grouping will allow students to support each other and discuss their findings as they explore the different tools. Students will use the visualization tools to determine the wavelengths associated with different electromagnetic waves and determine

the primary emission wavelengths for Sun and Earth and understand the role of greenhouse gases in trapping long-wave radiation and relation between global GHG concentrations and global temperature.

The outcomes of these activities are:

- 1) Gaining a familiarity of electromagnetic (EM) radiation by blackbodies
- 2) Understanding EM emission characteristics as a function of blackbody body temperature
- 3) Knowledge of EM radiation interaction with different gas molecules and recognition of greenhouse gases (GHGs)
- 4) Role of GHG concentrations in controlling Earth's atmospheric temperature.

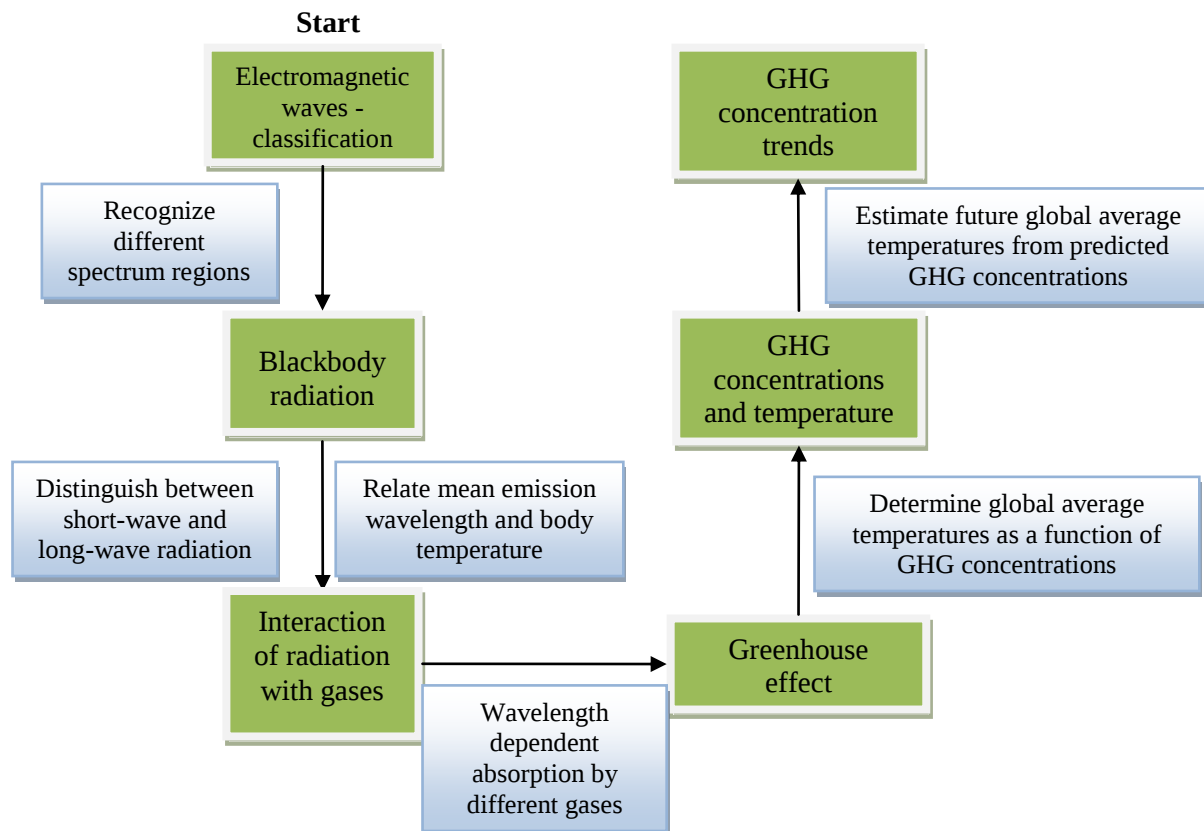


Figure 5: Flow of activities and information throughout this project

Implementation

Anticipatory Set – Assuming students have already been introduced to the general climate change vocabulary (e.g., GHGs, GHG emissions, Carbon footprint), begin the unit by having students explore what Earth’s source of energy is and how it is received. What differences in temperatures have the students noticed between cloudy and clear nights in winter? Once the students understand that Sun is the source of energy and that “heat” from Earth can escape to space, proceed to unit.

General Procedure

1. Using the [Electromagnetic spectrum applet](#) determine the wavelengths ranges associated with UV, visible, infrared, and microwave spectra.

The students should be allowed to explore the applet and familiarize themselves with the different terminologies of the EM wavelength spectrum. In particular, it is important to recognize the range of visible and near-visible wavelengths (UV, near-infrared), and the wavelengths associated with heat transmission (infrared, microwave).

2. Using the [blackbody spectrum applet](#), students should be able to determine the primary wavelengths corresponding to Sun’s and Earth’s EM radiation. The students should explore the applet and develop an understanding of the relationship between the temperature of a blackbody and its peak emission wavelength.

3. a. Use the applet illustrating the wavelength-dependent interaction between [different chemical compounds and electromagnetic radiation](#) to determine what makes a gas a greenhouse gas. Students should explore the applet, choosing different EM radiation types (UV, visible, infrared, or microwave) and selecting different molecules, to determine for themselves that some molecules may interact with EM radiation emitted from Earth, i.e., act as greenhouse gases. (This is more appropriate to 8th or 9th graders).

OR

- b. With the aid of a more advanced [applet](#) (Click on the link and then on the picture under “Collisional Heating by CO₂ in the Atmosphere”), students can explore in detail the absorption characteristics of different gases in the infrared wavelength regime. They can study the differences between different greenhouse gases with respect to their interaction with Earth’s emission spectrum. (This is more appropriate to high school students).

4. The [applet](#) on greenhouse effect helps students make the connection between greenhouse gases and Earth’s temperature. In this applet, interaction of an ideal atmosphere with incoming solar radiation and outgoing terrestrial radiation is considered. Students can vary the concentration of greenhouse gases in the atmosphere and determine the resultant average temperature of the modeled atmosphere. On completion of this unit, students should be able to explain the role of GHGs in regulating Earth’s temperature and the consequence of higher GHG concentrations on Earth’s future temperature.

Closure – By the end of the unit, the students should recognize the importance of the role of GHGs in keeping Earth warm enough for humans to survive and understand that the greenhouse effect is the result of absorption of long-wave radiation from Earth’s surface by some atmospheric gases. The students should also be able to list a few major greenhouse gases.

Learning Contexts

This module lend itself to upper level science courses. In Physics, wave lengths and the concept of electromagnetic radiation may be discussed in greater detail. It would also be appropriate to incorporate these activities with a chemistry lecture related to chemical bonds, photochemical reactions, etc.

Data graphing and graph interpretation could all be integrated into mathematics class as a real-world application of technology skills.

Science Standards

The following New York State, Mathematics, Science and Technology (MST) Standards are supported by this unit: (<http://www.p12.nysed.gov/ciai/standards.html>)

STANDARD – Analysis, Inquiry, and Design

Students will use mathematical analysis, scientific inquiry, and engineering designs, as appropriate, to pose questions, seek answers, and develop solutions.

- Abstraction and symbolic representation are used to communicate mathematically.

STANDARD 4 – The Physical Setting

Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

- Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity
- Energy exists in many forms, and when these forms change, energy is conserved
- Energy and matter interact through forces that result in changes in motion.

STANDARD 6—Interconnectedness: Common Themes

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

- Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.
- Equilibrium is a state of stability due either to a lack of change (static equilibrium) or a balance between opposing forces (dynamic equilibrium).
- Identifying patterns of change is necessary for making predictions about future behavior and conditions

Assessment

Assessment should be based on quizzes/homeworks/exams.

Other Resources and Files

- [Student summary worksheet](#)
- [Greenhouse effect PowerPoint presentation](#)

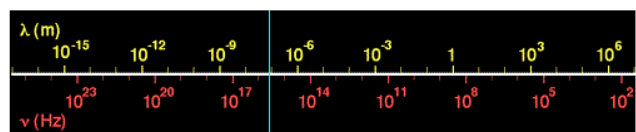
Case Study: Greenhouse effect

Electromagnetic (EM) Spectrum Worksheet

Directions:

- a. Go to the webpage -

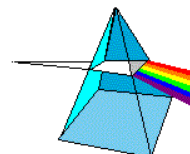
Applet: Spectrum



Wavelength = 9.061e-8 m = 90.61 nm
 Frequency = 3.308e15 Hz = 3308420.5 GHz
 Energy = 2.192e-18 J = 13.68 eV

Ultraviolet

Origin: Inner electron transitions
 Detection: Photo effect



<http://lectureonline.cl.msu.edu/~mmp/applist/Spectrum/s.htm>. This should provide access to the applet.

- b. The applet displays a scale with wavelengths and frequencies listed along it. Note that the wavelength unit here is meters ($1 \text{ m} = 10^6 \mu\text{m} = 10^9 \text{ nm}$).
- c. Click anywhere on the wavelength scale (black region) or drag the blue bar across the scale. The exact wavelength corresponding to the location of the blue bar is listed below the scale (in meters and nm). Also listed below the scale (in blue color) is the name of the spectrum associated with that wavelength.

Using the EM spectrum applet, answer the following questions:

1. Explore the [Electromagnetic spectrum applet](#) and fill out the table below relating the wavelength ranges associated with ultraviolet (UV), visible, infrared, and microwave spectra. Don't forget to include units (units conversion: $1 \text{ m} = 10^6 \text{ mm} = 10^9 \text{ nm}$; $1000 \text{ nm} = 1 \mu\text{m}$).

EM radiation spectrum	Min wavelength	Max wavelength
Ultraviolet	13 nm	300 nm
Visible	350 nm	750 nm
Infrared	800 nm	1000000 nm or 1000 μm
Microwave	1000 μm	0.277 m

2. What wavelength spectrum is associated with heat radiation? Do you know any devices that rely on detecting these wavelengths?

Heat radiation is in infrared wavelengths. Infrared detection is used in thermal imaging, night vision goggles, certain non-contact thermometers, etc. For examples see

http://coolcosmos.ipac.caltech.edu/cosmic_kids/learn_ir/index.html

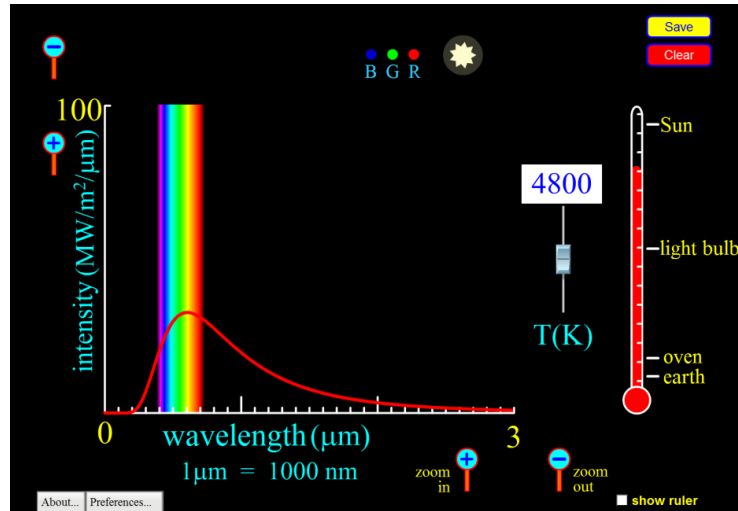
3. Arrange the spectrum ranges – infrared, UV, microwave, and visible – in the order of increasing wavelengths.

In the order of increasing wavelengths: UV, visible, infrared, microwave

Blackbody Spectrum Worksheet

Directions:

- Open the [blackbody radiation applet](http://phet.colorado.edu/en/simulation/blackbody-spectrum) (<http://phet.colorado.edu/en/simulation/blackbody-spectrum>).
- Select a temperature by moving the slider (start with “Sun”)



- Use the x-axis and y-axis zoom in and zoom out buttons until the blackbody emission spectrum becomes visible. Typical choices for axis limits are: (a) Sun: x-axis: 0 to 3 and y-axis: 0 to 100; (b) Earth: x-axis: 0 to 48 and y-axis: 0 to 0.0001.

Using the applet answer the following questions:

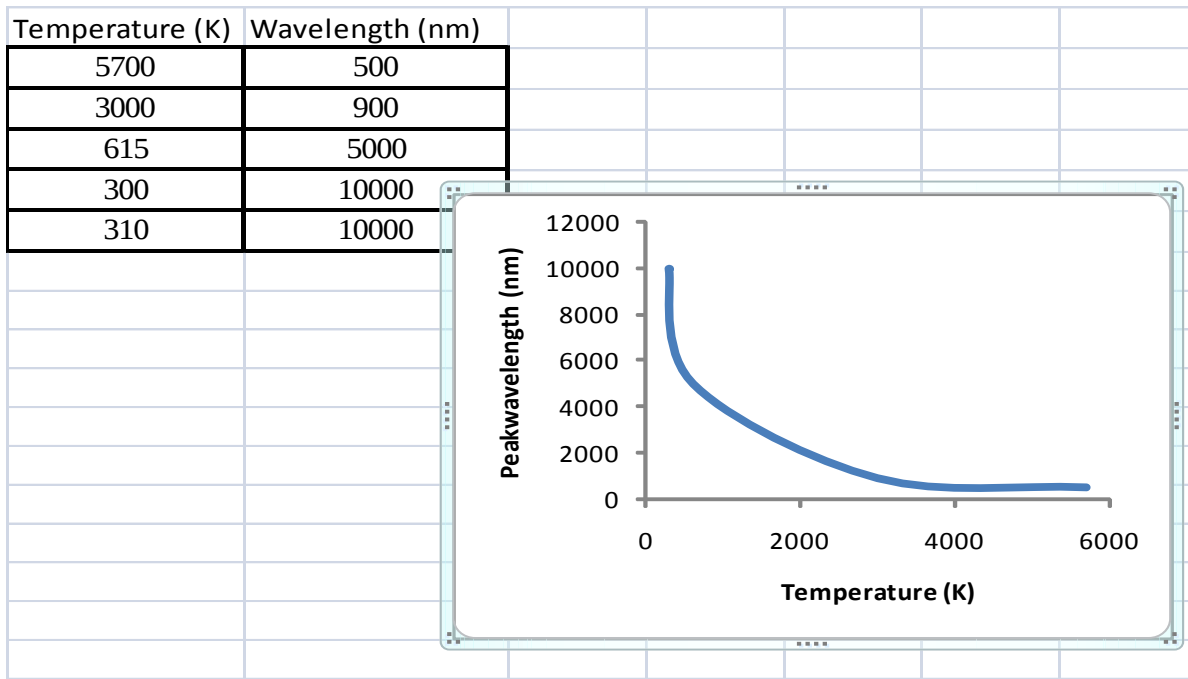
- Use the blackbody spectrum applet to fill out the table below:

Note that the *peak wavelength* is the x-axis value corresponding to the maximum of the blackbody intensity curve (red curve).

Object	Temperature	Peak wavelength	The primary peak spectrum region
Sun	5700 K	500 nm	visible
Light bulb	3000 K	900 nm	infrared
Oven	615 K	5 μm	infrared
Yourself	310 K	10 μm	infrared
Earth	300 K	10 μm	infrared

Note: Temperature units conversion: Fahrenheit (F) to Celsius (C): $C = (F - 32) * 5/9$; Celsius (C) to Kelvin (K): $K = 273 + C$

- Using Excel, plot the relationship between temperature and peak wavelength. Remember to label the axes.



3. Which of the above bodies mostly radiate light (i.e., emit EM radiation in the visible wavelengths) and which bodies will mostly radiate heat (i.e., emit EM radiation in the infrared regime). Recall the wavelengths associated with the visible and infrared spectrum.

Mostly light: Sun

Mostly heat: Light bulb, Oven, Earth, humans

4. The area under the curve (i.e. the size of the space under the red curve) represents the net energy radiated out of a blackbody at the selected temperature. Explore how the area under the curve changes with temperature.
- Assuming that the curve is a triangle, calculate the area of the triangle as the product of the *wavelength range* and *peak intensity*.

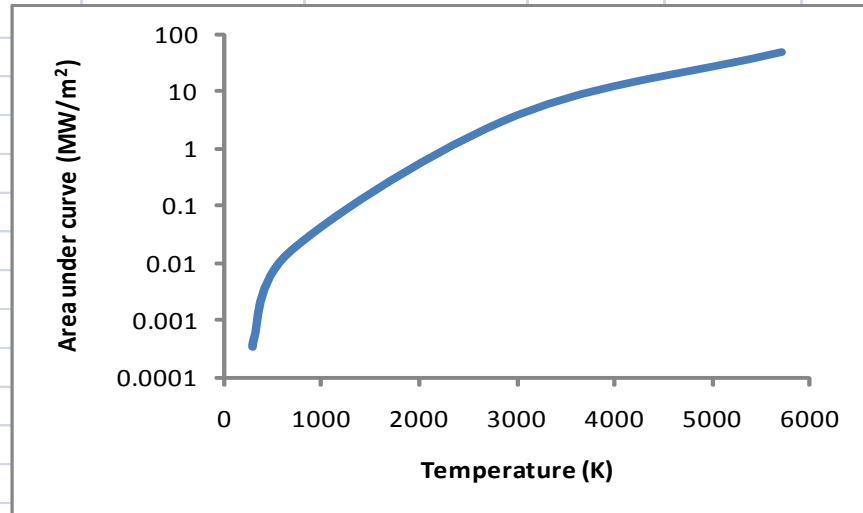
Peak intensity: The maximum y-axis value of the blackbody intensity curve.

Wavelength range: A blackbody emits radiation over all wavelengths, and thus there is no finite wavelength range associated with a blackbody radiation. Here, let's define wavelength range as the width of the blackbody intensity curve at half the peak intensity level.

- Using Excel, plot the Area under the curve as a function of body temperature. Remember to label the axes.

Object	Temperature	Peak intensity (MW/m ² /μm)	Wavelength range (μm)	Area under the curve (MW/m ²)
Sun	5700 K	80	0.6	48
Light bulb	3000 K	3.16	1.2	3.79
Oven	700 K	0.003	5.5	0.0165
Yourself	310 K	0.00004	11	0.00044
Earth	300 K	0.00003	11	0.00033

Object	Temperature (K)	Area under the curve (MW/m ²)
Sun	5700	48
Light bulb	3000	3.79
Oven	700	0.0165
Yourself	310	0.00044
Earth	300	0.00033



5. Do incandescent light bulbs (3000 K) radiate more light or more heat?

The net light from a blackbody is proportional to the area of the emission curve in the visible wavelengths (400-750 nm). The net heat from a blackbody is proportional to the area of the emission curve in the infrared regime ($\sim 1 - 100 \mu\text{m}$). For an incandescent light bulb, the area of the emission curve in the infrared regime is greater than the area in the visible regime, thus an incandescent light bulb generates more heat than light.

Atmospheric Gases and EM Radiation Worksheet

Directions:

- Open the [greenhouse gas and light applet](http://phet.colorado.edu/en/simulation/molecules-and-light) or go to link <http://phet.colorado.edu/en/simulation/molecules-and-light>
- Select a molecule (start with CO₂).
- Choose an EM radiation spectrum (i.e., select Microwave, infrared, visible, or ultraviolet option as desired).
- Move the slider on the lamp to start the flow of photons with energy (and wavelength) corresponding to the chosen spectrum.



Using the Atmospheric gases and EM radiation applet, answer the following questions:

- Fill out the table below. Write “yes” or “no” to indicate whether a molecule interacts with photons of the selected EM radiation spectrum
A molecule is considered to have interacted with photons of the selected EM radiation, if it absorbs the incident radiation and gets excited. Note that, as the molecule returns to its original state, it re-emits radiation in all directions.

Molecule	UV	Visible	Infrared	Microwave
CO	No	No	Yes	Yes
N ₂	No	No	No	No
O ₂	No	No	No	No
CO ₂	No	No	Yes	No
H ₂ O	No	No	Yes	Yes
NO ₂	Yes	Yes	Yes	Yes
O ₃	Yes	No	Yes	Yes

- Recall the wavelength range corresponding to Earth’s radiative emission. Which of the above molecules interacts with Earth’s EM radiation? What do we call this group of gases?

The Earth’s radiative emission is largely in the infrared regime. The gases that interact with infrared emission include: CO, CO₂, H₂O, NO₂, and O₃. These gases are often referred to as greenhouse gases.

3. In the applet, select CO₂ molecule and infrared wavelength spectrum. As CO₂ absorbs infrared radiation and re-emits radiation, can you see that some of the radiation is directed back towards the lamp? Describe how this is similar to what happens between Earth's surface and its atmosphere with CO₂ molecules.

The Earth's temperature is such that it emits primarily in the infrared regime. As the infrared emission from Earth's surface is absorbed by carbon dioxide molecules (and other greenhouse gas molecules) in the atmosphere, they get excited, and then re-radiate the absorbed energy as infrared emission. Some of this re-radiated energy is directed back to Earth's surface, thus increasing the net energy received at the surface of Earth.

4. Which of the above molecules interacts most significantly with microwaves? How is this knowledge used in everyday cooking?

Water molecules effectively absorb microwave radiation, making them a necessary ingredient in microwave cooking. Water (externally added or already existing in vegetables) gets heated by absorption of microwaves and the neighboring molecules get heated on collision with the hot water molecules.

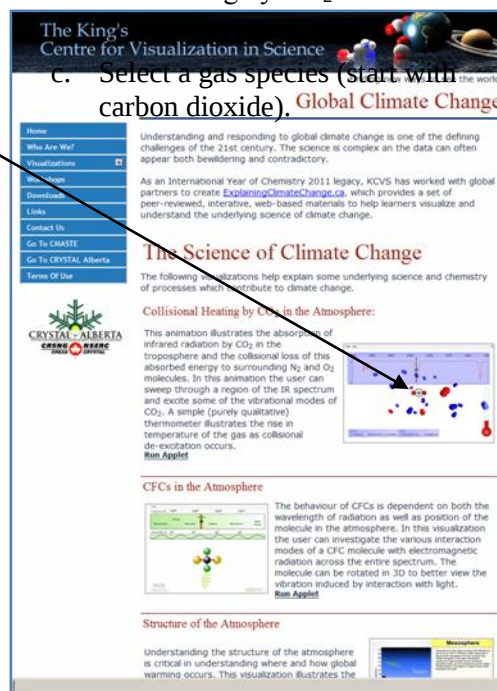
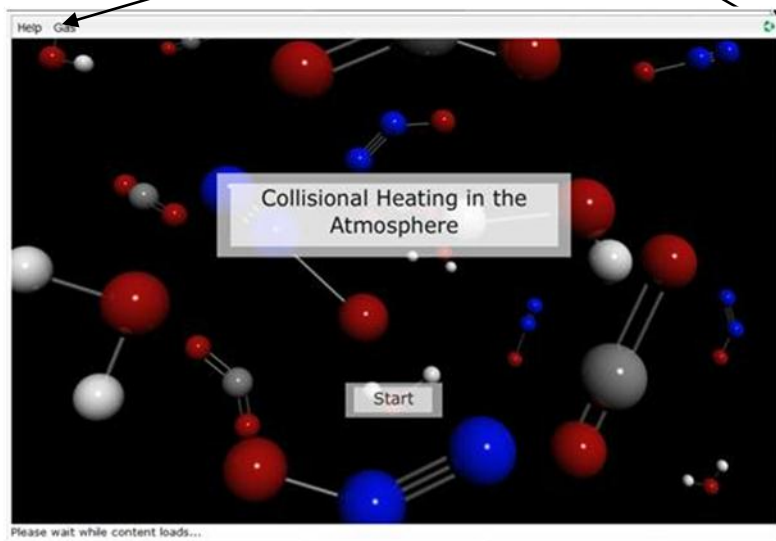
5. Does ozone interact with solar radiation? In what wavelength range? How is this interaction important for life on Earth?

Yes, ozone interacts with solar radiation, by absorbing UV light (wavelengths smaller than ~ 350 nm). This action of ozone protects us from the harmful effect of exposure to UV radiation.

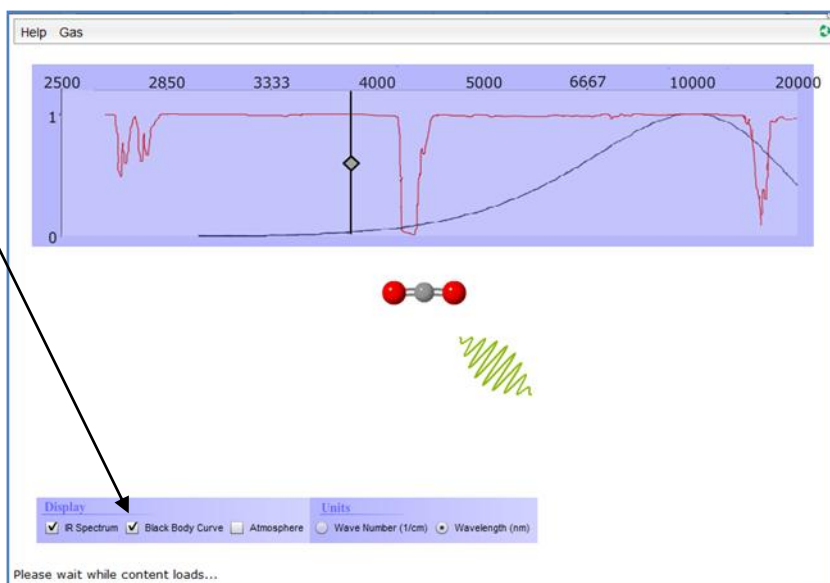
Greenhouse Gases and EM Radiation Worksheet

Directions:

- Open the [greenhouse gas applet link](http://www.kcvs.ca/site/projects/chemistry_files/CO2/co2new.swf) (http://www.kcvs.ca/site/projects/chemistry_files/CO2/co2new.swf)
- If the website homepage opens up, click on the picture under “Collisional Heating by CO₂ in the Atmosphere”.



- Click on Start
- In the bottom of the screen, click on choices of: IR spectrum and wavelength (nm).
- Waves/particles with energies corresponding to the selected wavelength will pass near or through the selected molecule.



Using the Greenhouse Gases and EM Radiation applet, answer the following questions:

- Under the “Gas” option in the menu bar, select Carbon Dioxide. Move the vertical bar (with a diamond symbol at the center) to different wavelengths and notice the behavior of the molecule at these wavelengths. What do you think the red line represents? How does the molecule behave when the

value of red line is ~ 1 (for example at a wavelength of 4300 nm)? And when it's ~ 0 (for example at a wavelength of 3333nm).

The red line is the infrared (IR) absorption spectrum of the selected molecule. A value of ~ 1 indicates no absorption, i.e., wavelengths which pass through the molecule unaffected. A value of ~ 0 indicates strong or complete absorption of energy at those wavelengths, i.e., these wavelengths are not allowed to pass through the molecule.

- Set the diamond bar to a wavelength of 4300 nm. Click on the "Atmosphere" button in the bottom of the screen to visualize the interaction between the excited molecule and the neighboring molecules in the atmosphere. How does an excited molecule return to its original state?

The heat from the excited carbon dioxide molecule is transferred to its neighboring N_2 and O_2 molecules in the atmosphere via molecular collisions. The CO_2 molecule eventually reaches the same temperature as the background atmosphere. The warm CO_2 and neighboring molecules radiate EM energy in all directions, some of which reach Earth's surface.

- Write the important absorption wavelengths associated with the different molecules in the table below.

Species	Absorption Wavelengths (nm)
CO_2	4200, 15000
H_2O	6000, 6700
N_2O	4500, 8000, 17000
O_2	None
N_2	None

- Which of the gases in the chart above have absorption wavelengths corresponding to Earth's blackbody radiation? What is this common terminology used to refer to this group of gases?

CO_2 , H_2O , and N_2O . These gases are commonly referred to as greenhouse gases.

- In the above list of gases, which ones are not greenhouse gases?

O_2 and N_2 .

- The different greenhouse gases in the above table (CO_2 , H_2O , and N_2O) absorb EM radiation in different wavelengths. Select CO_2 molecule and display Earth's blackbody radiation curve. Considering Earth's blackbody radiation curve, which of the CO_2 absorption modes may be more important for determining Earth's temperature?

The absorption mode closer to the peak of the Earth's radiation curve (i.e., the one at 15,000 nm) may be the more important absorption peak from the perspective of Earth's atmospheric temperature.

7. In this applet, the interaction of packets of EM radiation with an individual molecule is demonstrated. Would the net absorbed energy change, if the number of molecules is increased to two?

EM radiation packets will be absorbed if the path of the molecule coincided with that of the energy packet. If the number of molecules is increased, more energy packets would be intercepted and thus more energy would be absorbed.

8. Considering the current concentrations of major greenhouse gases, (http://cdiac.ornl.gov/pns/current_ghg.html): Note that the units of concentration are parts per million (ppm), parts per billion (ppb), and parts per trillion; 1 ppm = 1000 ppb = 10^6 ppt), which greenhouse gas may be the most important in determining Earth's temperature?

The current concentrations of major greenhouse gases are:

Carbon dioxide (CO₂): 389 ppm

Methane (CH₄): 700 ppb

Nitrous oxide (N₂O): 270 ppb

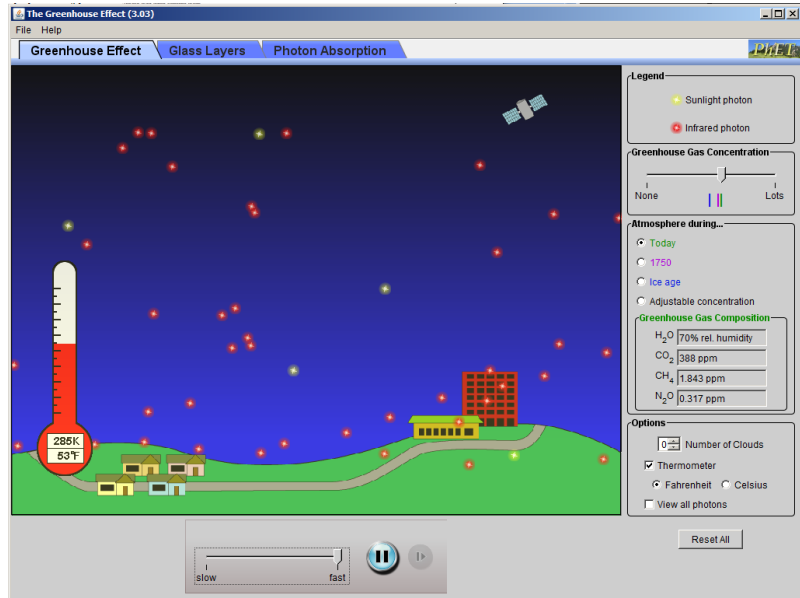
Tropospheric ozone (O₃): 25 ppb

As the concentration of a greenhouse gas determines the net energy absorbed, CO₂ is the most important greenhouse gas in Earth's atmosphere.

Greenhouse Gases and Earth's Temperature Worksheet

Directions:

- Open the [greenhouse effect applet](http://phet.colorado.edu/en/simulation/greenhouse) or click on <http://phet.colorado.edu/en/simulation/greenhouse>
- Slide the “Greenhouse Gas Concentration” option to “none”, i.e., select a CO₂ concentration of 0.
- Note the temperature on the thermometer.
- Vary the greenhouse gas concentrations by selecting different time period options (by selecting options under “Atmosphere during”).
- Note the temperatures and CO₂ concentrations for the different settings.
- Lastly, slide the “Greenhouse Gas Concentration” option to “Lots”, i.e., select a “very high” CO₂ concentration.

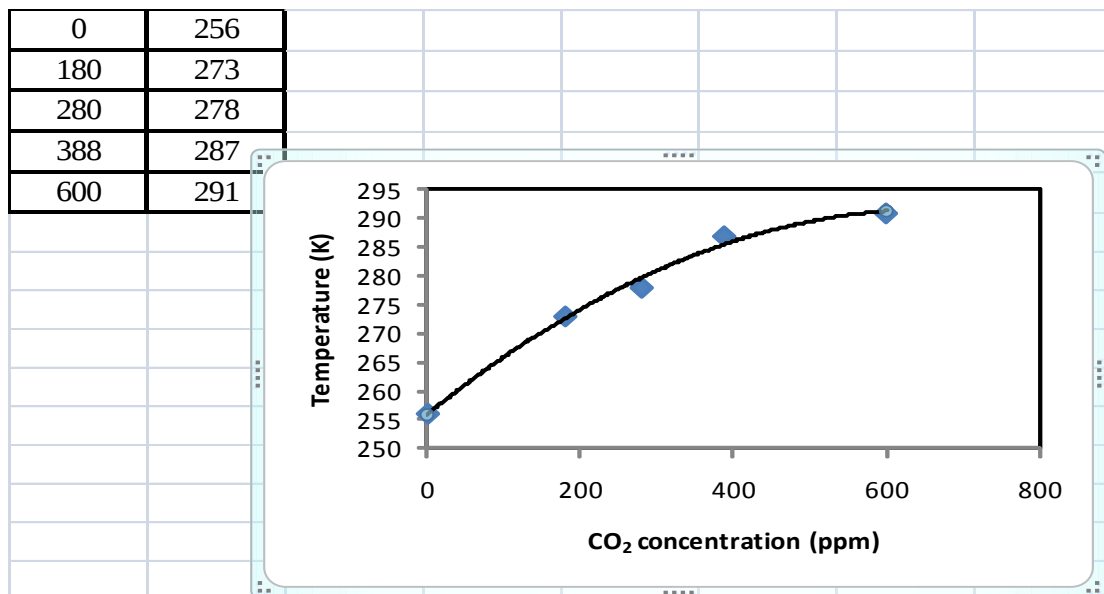


Using the greenhouse gases and Earth's temperature applet, answer the following questions:

- What do the yellow stars represent? What primary wavelengths do the yellow stars correspond to?
The yellow stars represent the photons (energy particles) from Sun that reach Earth. These photons are primary in the visible wavelengths.
- What do the red stars represent? What wavelength do the red stars correspond to?
The red stars represent photons emitted by Earth. As Earth's electromagnetic radiation is primarily in wavelengths longer than 4 μm , these stars have wavelengths in the infrared regime.
- Under “Atmosphere during ...” click on “Ice age”. Observe the motion of yellow photons. In what direction(s) (up or down) do they travel?
The yellow photons travel downwards from Sun towards Earth and are absorbed by the Earth's surface in the “brown regions” and reflected back towards the Sun in “white regions” where ice is present.
- Under “Atmosphere during ...” click on “Today”. Observe the motion of red photons. In what direction(s) (up or down) do they travel?
The red photons, in general, travel from Earth to space. When greenhouse gases are present, Earth's EM radiation is absorbed by these gases and some of the infrared radiation from the warm atmosphere is re-directed back towards the Earth.
- Complete the table below (for the “Future” scenario (600 pm) move the greenhouse gas slider bar to half-way between “Today” and “Lots”):

Atmosphere during	CO ₂ concentrations	Earth's temperature
-	0	256 K
Ice age	180 ppm	273 K
1750	280 ppm	278 K
Today	388 ppm	287 K
Future	600 ppm	291 K

6. Using Excel, plot temperature (y axis) as a function of CO₂ concentrations (x-axis). Remember to label the axes. (Use a value of 600 ppm to represent a “very high” concentration.)



7. How are the numbers of infrared photons coming back to Earth related to the concentration of greenhouse gases? Explain why.

As the concentration of greenhouse gases are increased, more of Earth's electromagnetic infrared radiation is absorbed by the atmosphere, making the atmosphere warmer. A warmer atmosphere radiates more effectively, resulting in an increased re-radiation of infrared photons from the atmosphere to Earth's surface.

8. What does the addition of clouds do to the Earth's average temperature? (Increase the “number of clouds” on the right corner of the applet, from 0 to 3.) How do the cloud layers interact with the solar and infrared photons?

The temperature of Earth decreases slightly because of the reflection of sunlight by the clouds.

Unit Home (title)

Teaching Notes

Case Study

Step-by-Step

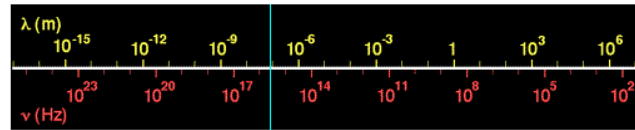
Tools and Data

Step-by-Step

Part 1: Electromagnetic spectrum

1. Click on this [link](#).
2. Click on the wavelength scale.
3. Students can list all the names of the wavelength spectrum listed below the scale with the approximate wavelength range for each of them. Note that it would be better to use nm or μm as the unit of wavelength (it is expected that students will be able to convert to these units from meters).
4. Note some examples related to the different spectrum ranges.

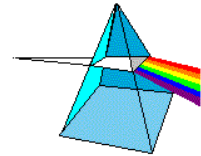
Applet: Spectrum



Wavelength = $9.061\text{e-}8\text{ m}$ = 90.61 nm
Frequency = $3.308\text{e}15\text{ Hz}$ = 3308420.5 GHz
Energy = $2.192\text{e-}18\text{ J}$ = 13.68 eV

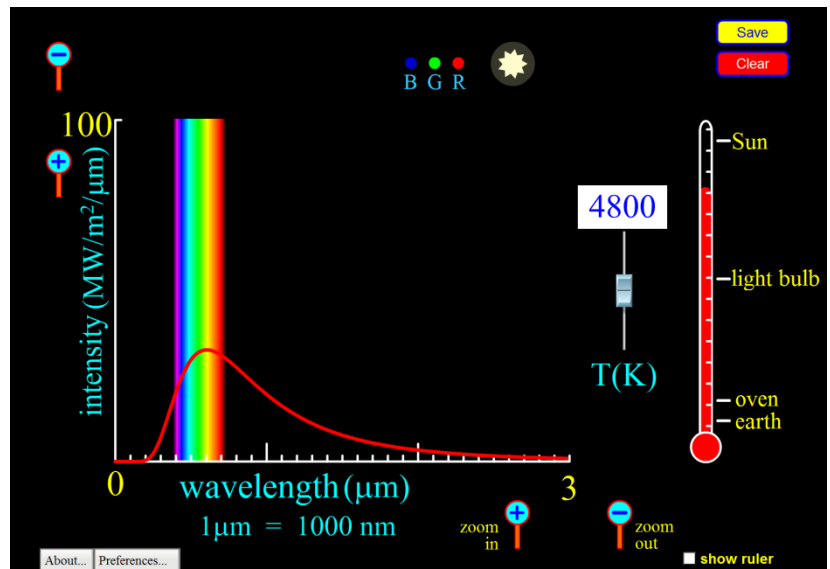
Ultraviolet

Origin: Inner electron transitions
Detection: Photo effect



Part 2: Blackbody radiation

1. Open the [blackbody radiation applet](#).
2. Select a temperature by moving the slider
3. Click on the x- and y-axis zoom in and zoom out buttons until the blackbody emission spectrum becomes visible. Typical choices: Sun: x-axis: 0 to 3 and y-axis: 0 to 100; Earth: x-axis: 0 to 48 and y-axis: 0 to 0.0001
4. Note the wavelength location of the maxima of the radiation spectrum curve
5. Change the temperature and repeat steps 3 and 4.
6. Complete the discussion questions on the student summary sheet.



Part 3a: Greenhouse gas interaction with EM radiation (middle school students)

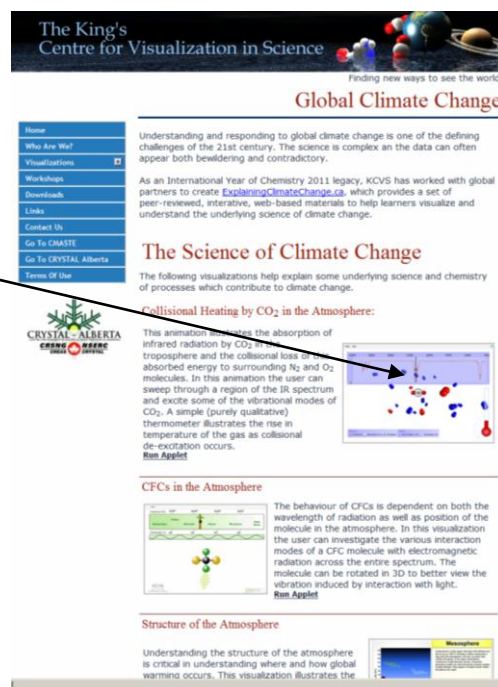
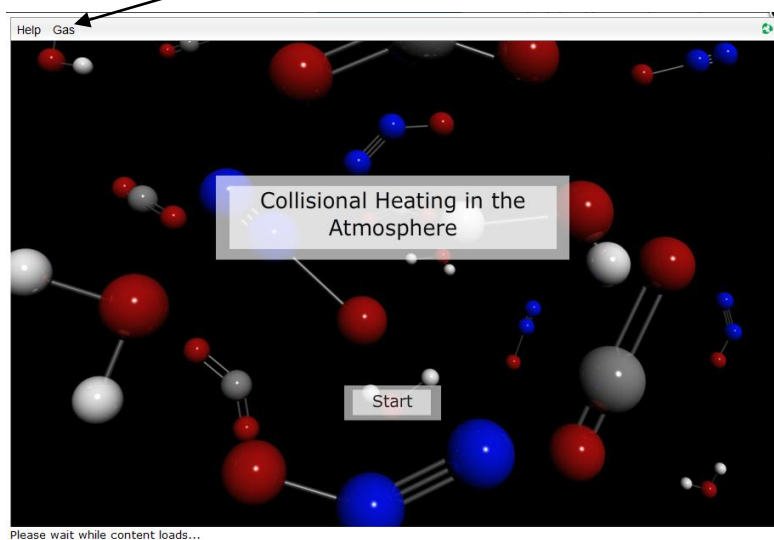
1. Open the [greenhouse gas and light applet](#)
2. Select a molecule.
3. Choose an EM radiation spectrum

- Move the slider on the lamp to start the flow of particles with energy corresponding to the chosen spectrum.
- Note if the molecule interacts with the selected spectrum. An interaction is characterized by the excitation of the molecule because of the absorption of the incident energy. As the molecule returns to its original state, it re-emits radiation. Notice that the radiation is emitted out in all directions.
- Choose a different EM radiation spectrum
- Repeat steps 4 and 5.
- Repeat steps 4-7 with all the different molecules
- Fill out the table identifying the interaction between the different molecules and EM radiation spectrum ranges.
- Complete the discussion questions on the student summary sheet.

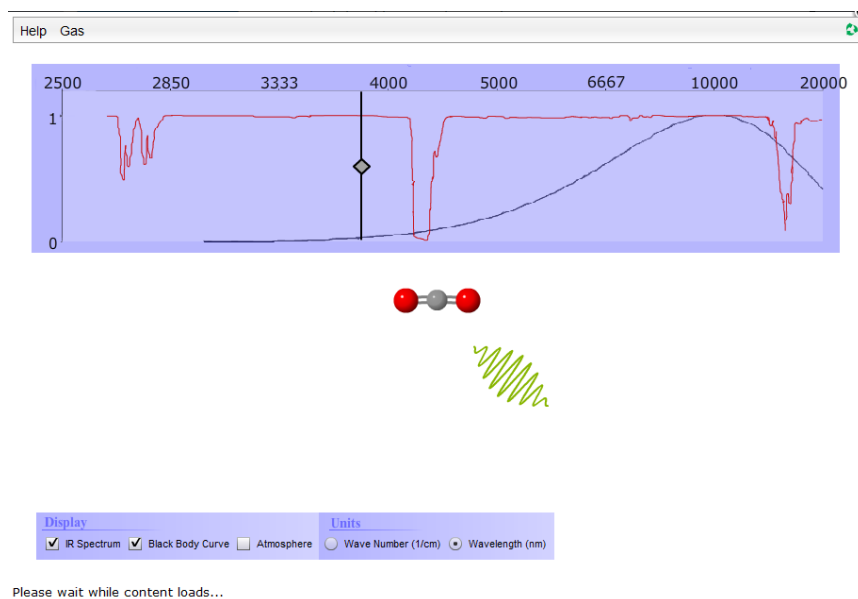


Part 3b: Greenhouse gas interaction with EM radiation (high school students)

- Open the [greenhouse gas applet link](#)
- Click on the picture under "Collisional Heating by CO₂ in the Atmosphere".
- Select a gas species.

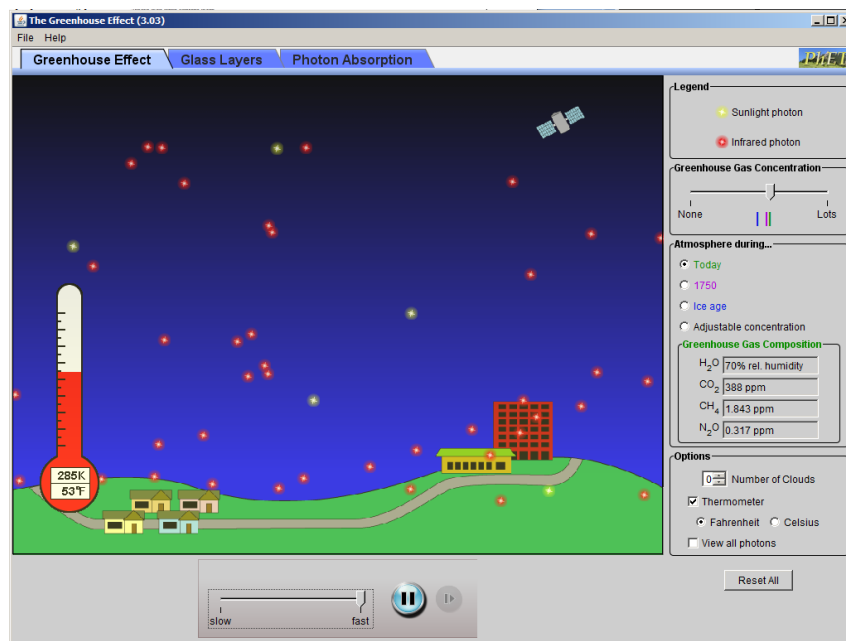


- Click on Start.
- The window will now display the infrared (IR) absorption spectrum of the selected molecule. Note that the molecule only absorbs in selected wavelengths in the IR range.
- In the bottom of the screen, click on IR spectrum, Black body curve, and wavelength (nm).
- Waves/particles with energies corresponding to the selected wavelength will pass near or through the selected molecule. If the wavelength of the EM radiation corresponds to the absorption spectrum of the molecule, then the molecule may absorb the energy, get excited, and re-radiate the energy or lose the energy by interaction with the atmosphere (click on the "Atmosphere" button in the bottom of the screen to visualize the collisional interaction between the excited molecule and the other molecules in the atmosphere).
- Note the absorption wavelength of the selected molecule corresponding to the EM emission spectrum of the Earth (Black body curve on the screen).
- Repeat for different selections of gas molecules.
- Complete the discussion questions on the student summary sheet.



Part 4: Greenhouse effect

- Open the [greenhouse effect applet](#).
- Set the greenhouse gas concentration to "none".
- Note the temperature on the thermometer.
- Increase the greenhouse gas concentrations to 1750 (pre-industrial) levels.
- Note the temperature on the thermometer.
- Observe the motion of the Sunlight and infrared photons. Note that infrared photons can be seen to be headed up from Earth's surface (blackbody emission) as well as headed down towards Earth's surface (greenhouse effect).
- Increase the greenhouse gas concentrations to other values (ice age and high) and note down the connection between greenhouse gas concentrations and temperatures.
- Complete the discussion questions on the student summary sheet.



Unit Home (title)

Teaching Notes

Case Study

Step-by-Step

Tools and Data

Tools and Data

Tool – Electromagnetic spectrum applet

<http://lectureonline.cl.msu.edu/~mmp/applist/Spectrum/s.htm>

Tool – Blackbody radiation applet

<http://phet.colorado.edu/en/simulation/blackbody-spectrum>

Tool – Greenhouse gas and light interaction applets

<http://phet.colorado.edu/en/simulation/molecules-and-light>

http://www.kcvs.ca/site/projects/chemistry_files/CO2/co2new.swf

Tool – Greenhouse effect and temperature applet

<http://phet.colorado.edu/en/simulation/greenhouse>

Data – Greenhouse gas concentrations

http://cdiac.ornl.gov/pns/current_ghg.html